Temporal and spatial variability of Great Lakes ice cover, 1973-2010

Jia Wang

NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan USA

Jia.wang@noaa.gov

Contributors/Collaborators:

Xuezhi Bai, Haoguo Hu, CILER, University of Michigan Ann Arbor

Anne Clites, Marie Colton, Brent Lofgren (GLERL)

The State of Lake Michigan, Michigan City, Sep. 26-28 2011

Support from GLRI is acknowledged

GLERL
Great Lakes Environmental Research Laboratory

CILER
Cooperative Institute for Limnology and Ecosystems Research
University of Michigan

Outline

I. Background/Motivation

II. Data

III. Results: Interannual variability, seasonal cycle, trend, spatial and temporal change, and periodicity

IV. ENSO and NAO/AO interference

V. Summary

I. Motivation

Great Lakes are complex, "mini climate system" including

--regional climate/atmosphere

--hydrosphere/

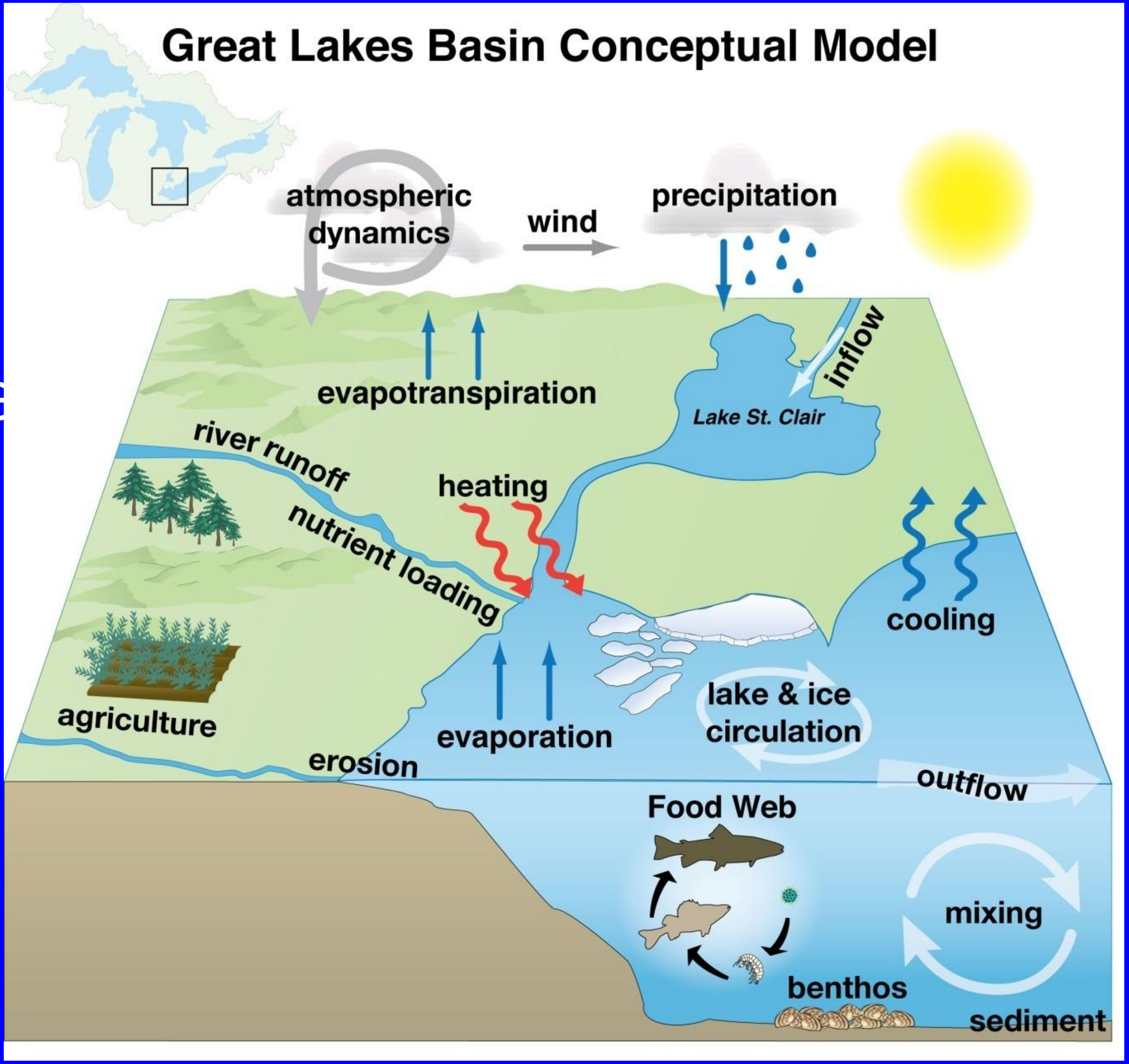
hydrodynamics,

--cryosphere (lake ice),

--biosphere/aquatic ecosystems, and

--land processes

(hydrology, coastal erosion)



Great Lakes watershed, with spatial change in depth, orientation

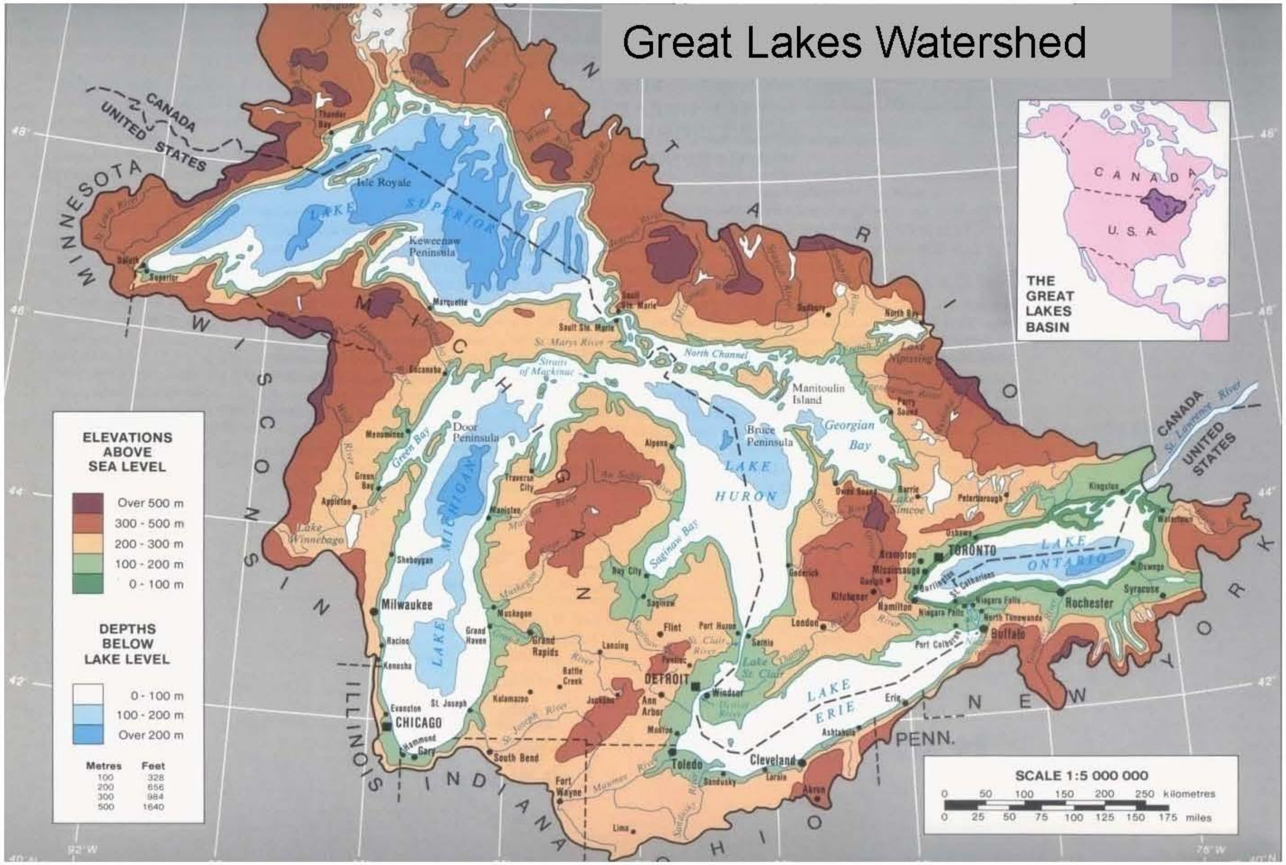
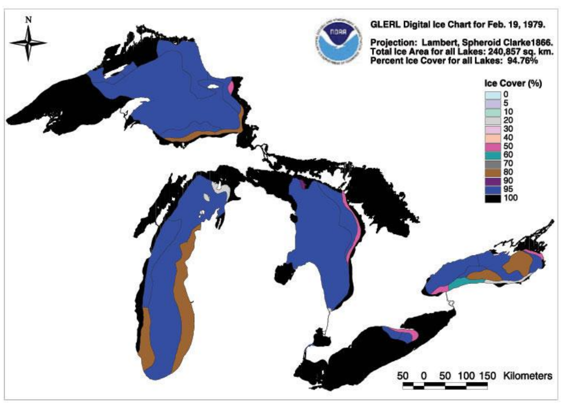
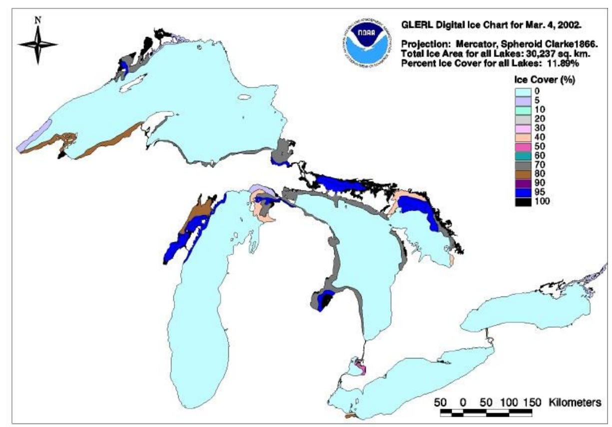


Figure 1. The Great Lakes watershed and topography. The average lake water depths (surface areas) for Lakes Superior, Michigan, Huron, St. Clair, Erie, and Ontario are 148 (82400), 84 (58000), 59(59596), 3(1114), 19(25744), and 85(19500) m (km^2), respectively.

Background

- Great Lakes Ice cover affects regional economy, ecosystem and water balance
- Ice cover has large inter-annual variability. In 1979, it was 95% and 11% in 2002.



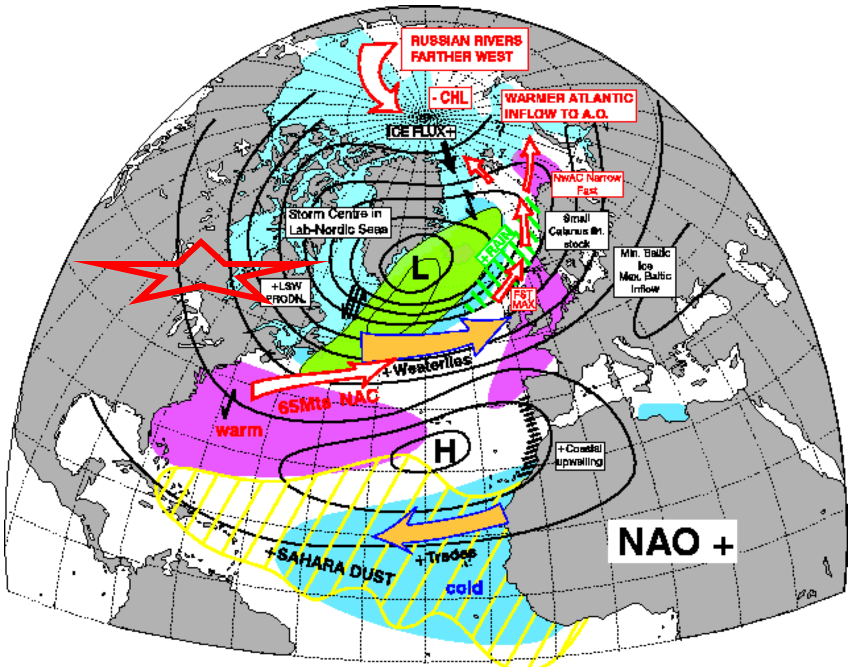


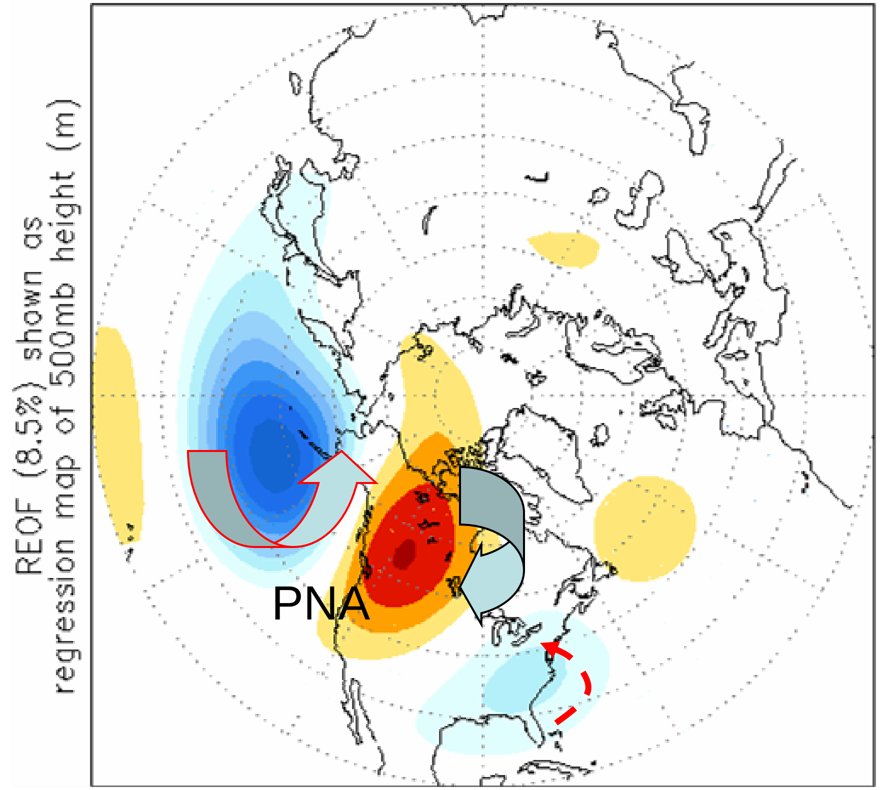
Max in 1979 95%

Max in 2002 11%

Natural Climate Teleconnection Patterns

Sea/lake ice as indicator of
climate changes: NAO/AO, ENSO/ PNA





The relationship between SAT, lake ice with ENSO and AO/NAO, and the interference of these two forcings

However, the impacts of ENSO and AO/NAO on the Great Lakes may not always be significant. Because GLs are at the edge of active centers of teleconnection patterns (PNA and NAO). Any distortion and the shift of the centers may result in different responses.

II. Data

1 38 yrs (1973-2010) Great Lakes ice coverage (in percentage)

2 NCEP/NCAR reanalysis atmospheric fields
1948-2010 monthly

3 Climate indices

(1) ENSO: Nino3.4 index (Averaged SSTA over 5 N to 5S, 170W to 120W) from NOAA CPC (Climate Prediction Center) 1950-2010

(2) NAO index
The NAO is defined as the normalized pressure difference between a station on the Azores and one on Iceland. CRU,UK

Based on the following research papers

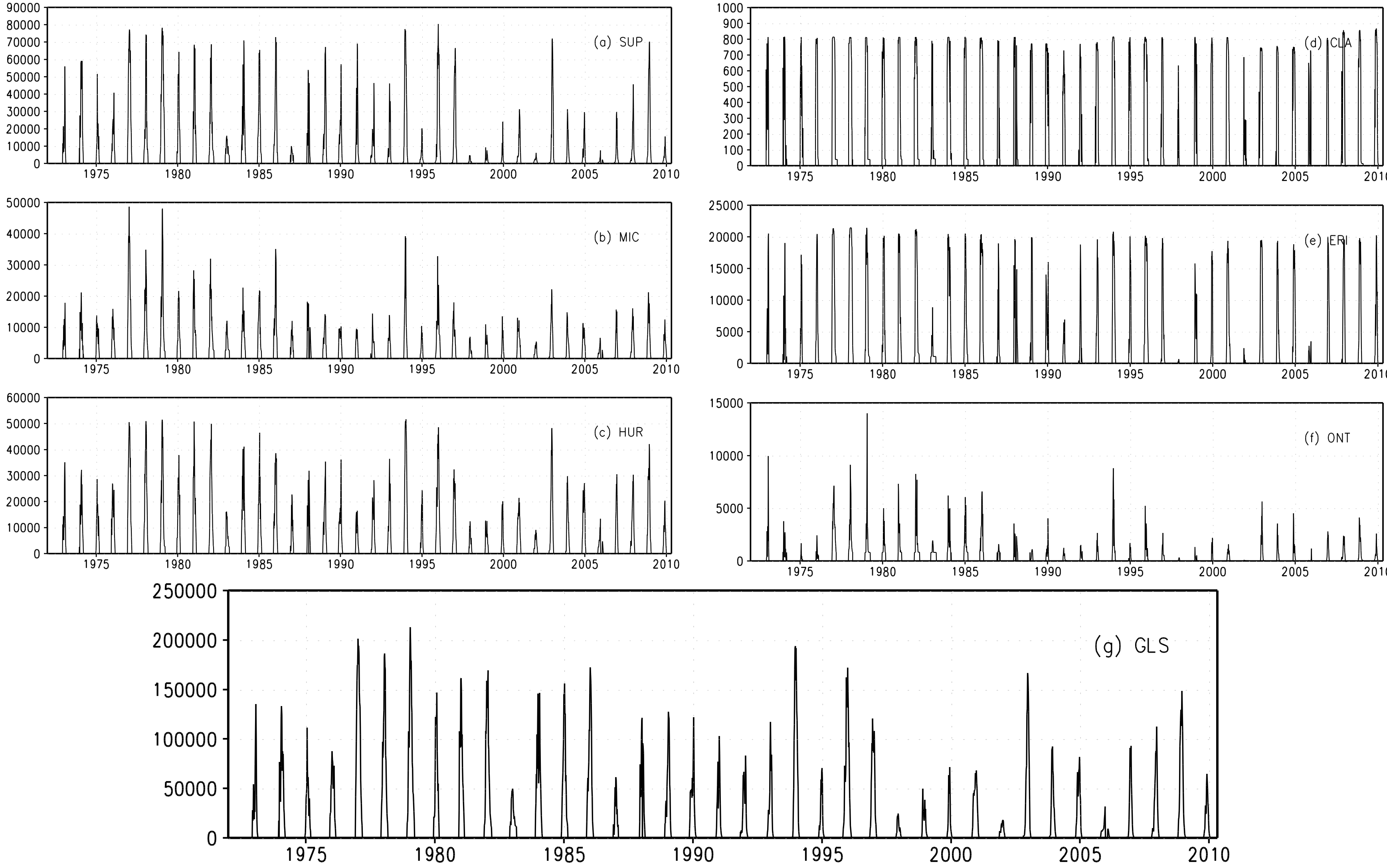
Wang, J., X. Bai, G. Leshkevich, M. Colton, A. Clites, and B. Lofgren, 2010: Severe Great Lakes ice cover in winter 2008/09: Contribution of AO and ENSO, AGU *EOS, 91 (5), 41-42.*

Wang, J., X. Bai, H. Hu, A. Clites, M. Colton, and B. Lofgren, 2011. Temporal and spatial variability of Great Lakes ice cover, 1973-2010. J. Clim., (in press)

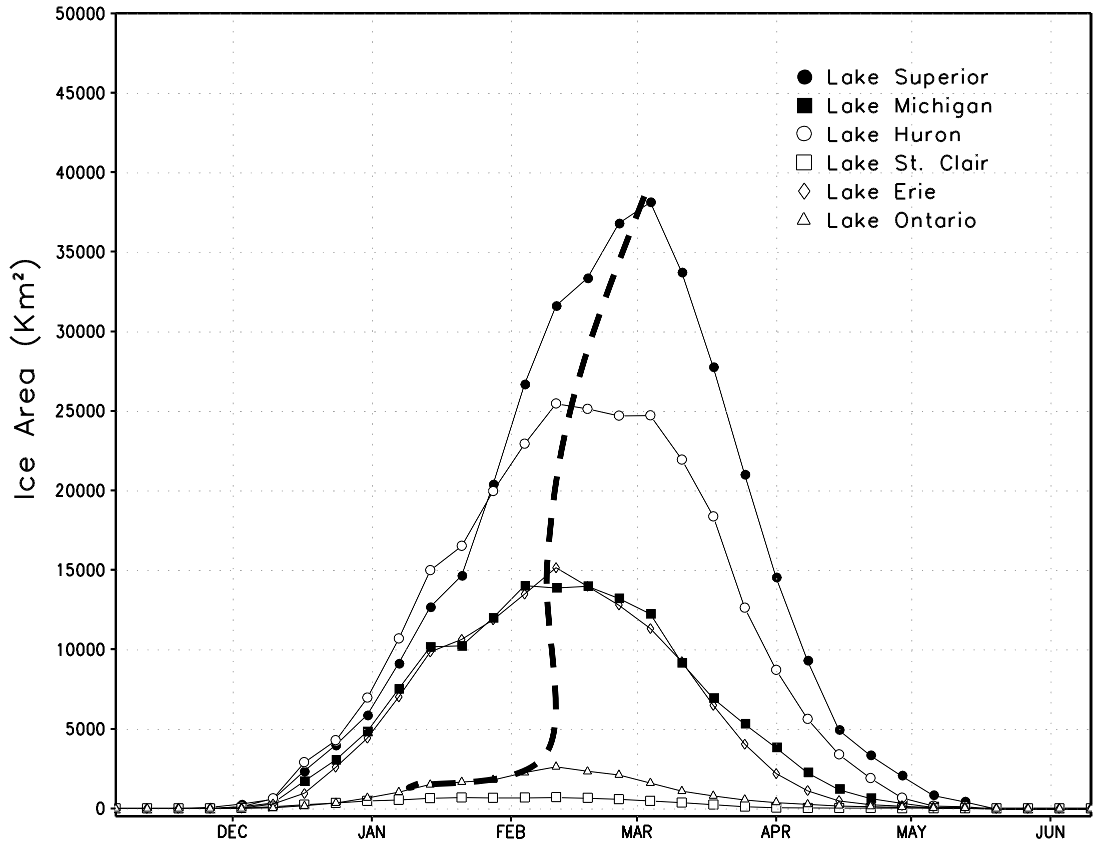
Bai, X., J. Wang, C. Sellinger, A. Clites, R. Assel, 2010. The impacts of ENSO and AO on the interannual variability of Great Lakes ice cover (accepted to *JGR*)

III. Results: Interannual variability:

Great Lakes Ice cover in 2008/09 winter reached the 2003 level! (weekly ice area in km**2)



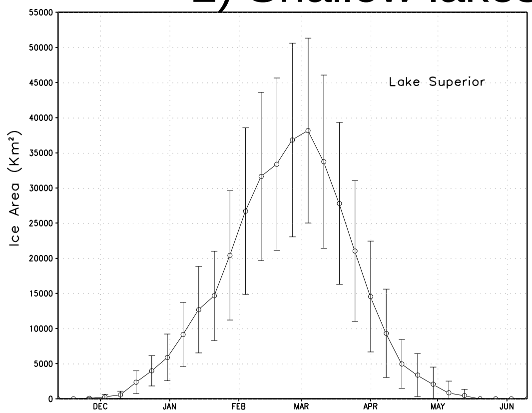
Seasonal cycle

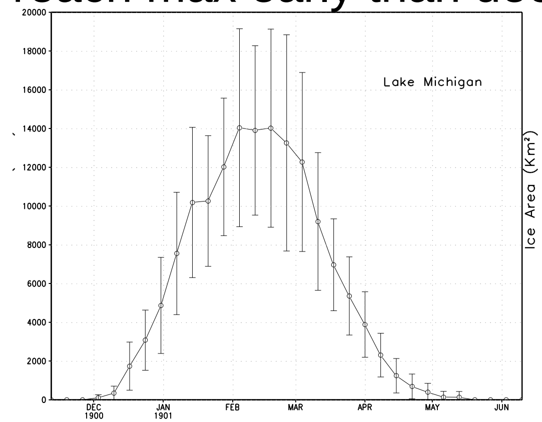


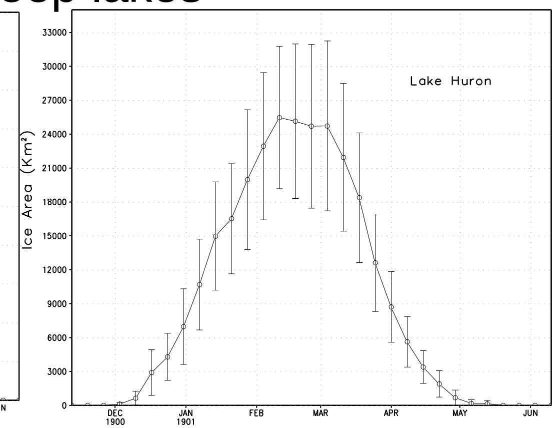
Climatology and STDs:

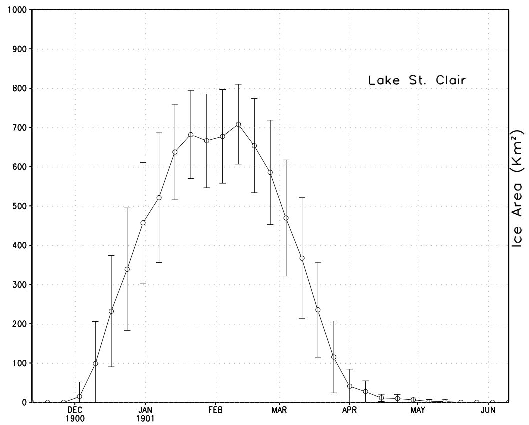
Characteristics: 1) STD> or ~ mean!—large natural variability➔difficult for a long-term prediction!

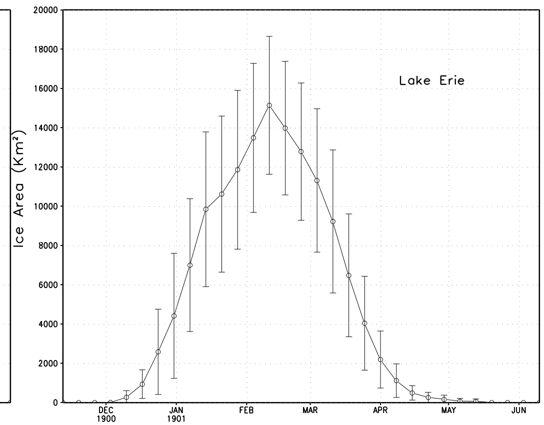
2) Shallow lakes reach max early than deep lakes

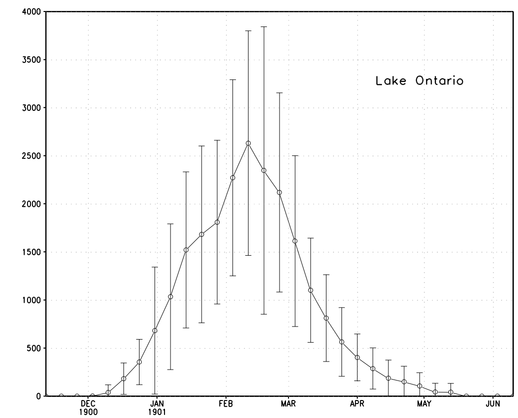






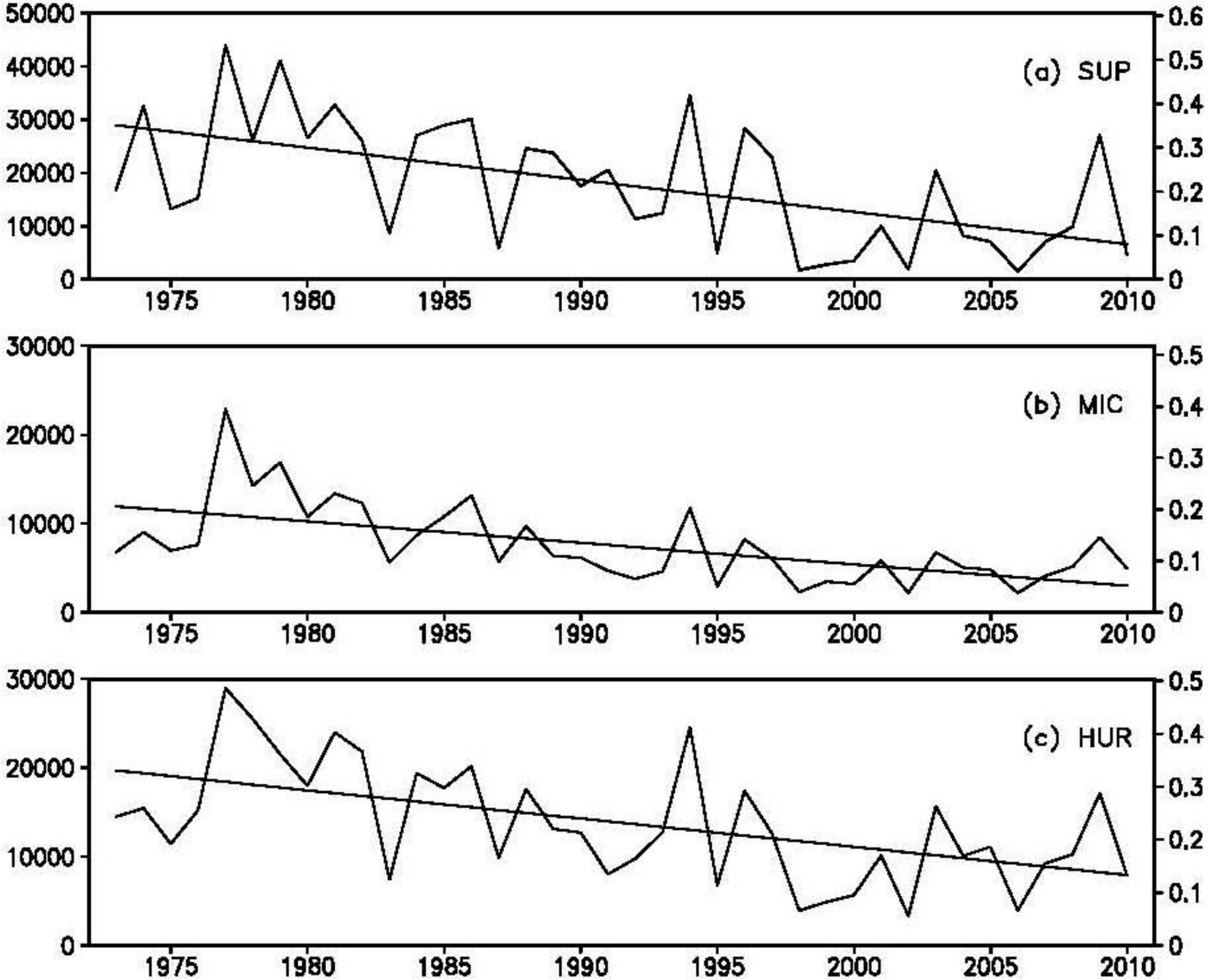




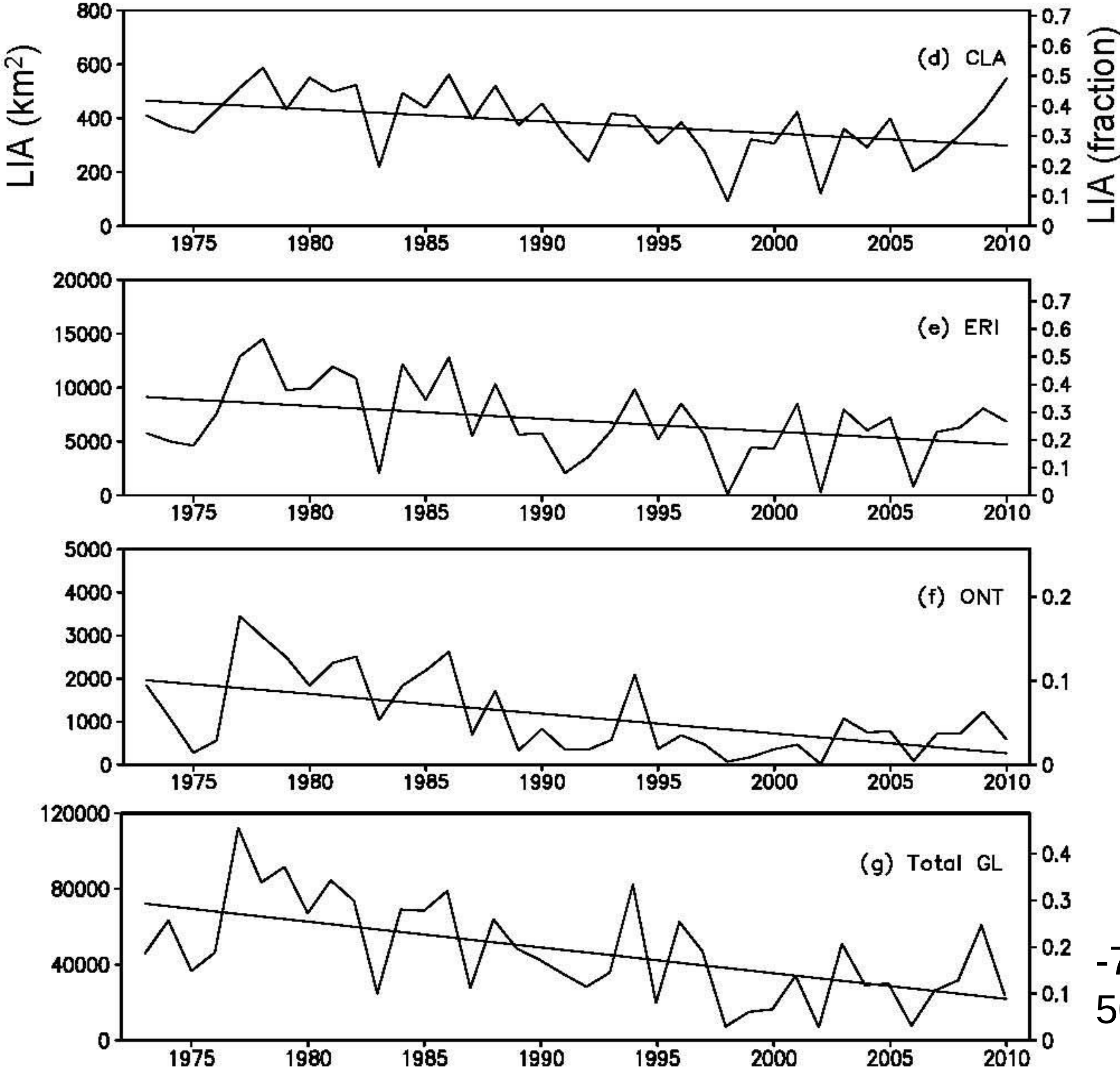


Upper Lakes Ice Cover, 1972/73-2009/10 based on least square fit

	Wang et al. 2011, in press	Total Loss
(a) SUP	-2.07%/Yr	-79%
(b) MIC	-2.025%/Yr	-77%
(c) HUR	-1.64%/Yr	-62%



Lower Lakes Ice Cover, 1972/73-2009/10



Wang et al. 2011, in press | **Total Loss**

--0.962%/Yr **-37%**

--1.303%/Yr **-50%**

--2.328%/Yr **-88%**

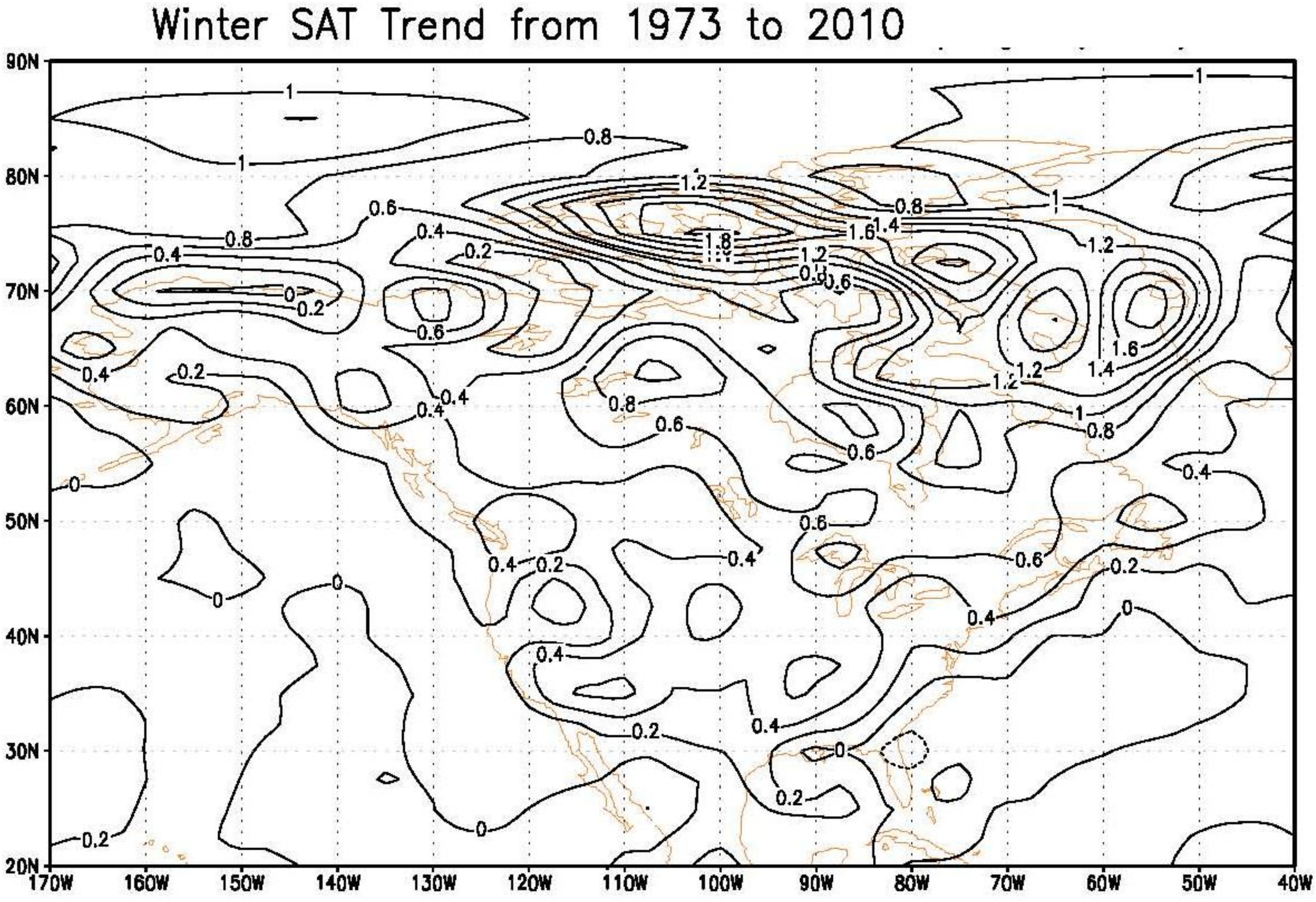
--1.862/Yr **-71%**

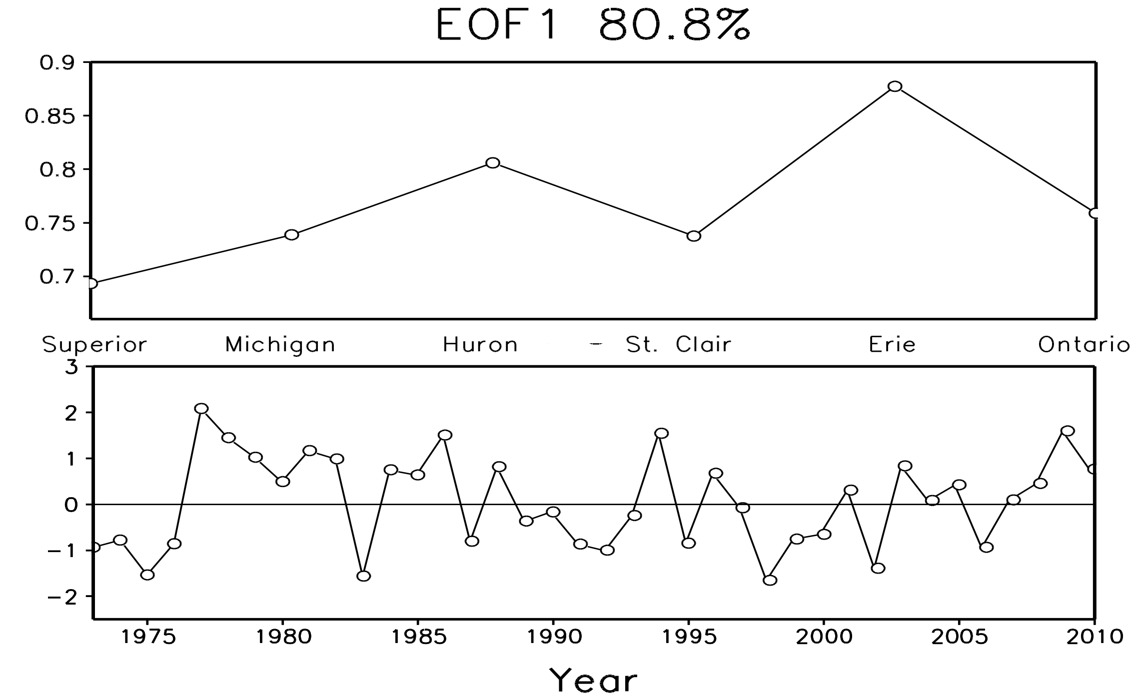
-79 -77 -62

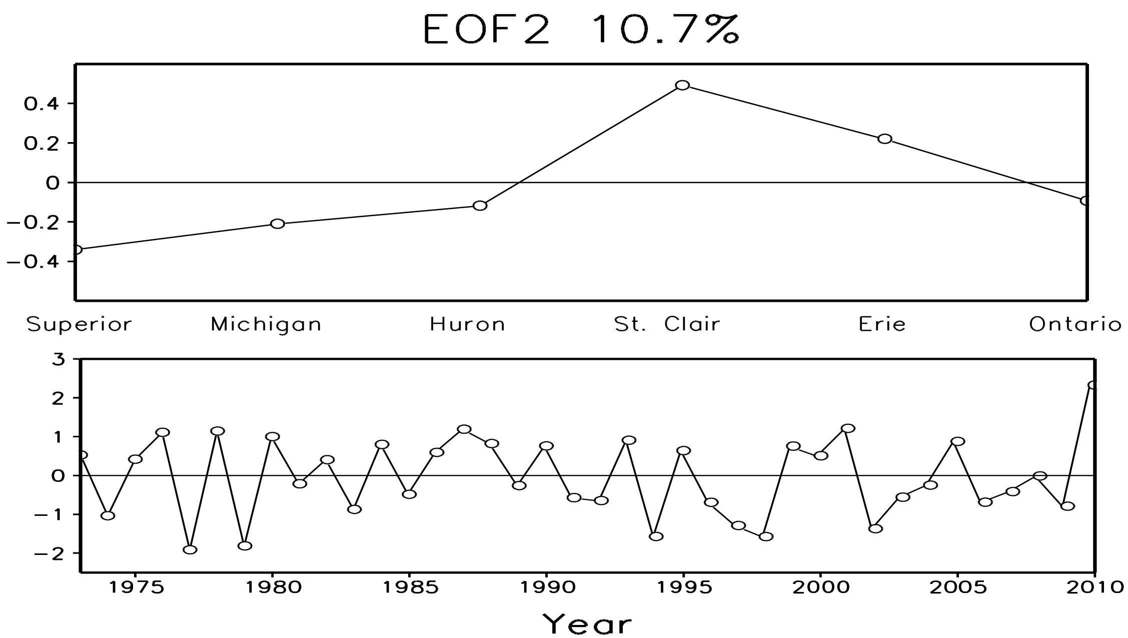
50 -88 -71

Why? Warming trend!

Upper GLs: 0.6C/Decade; Lower GLs: 0.4C/Decade





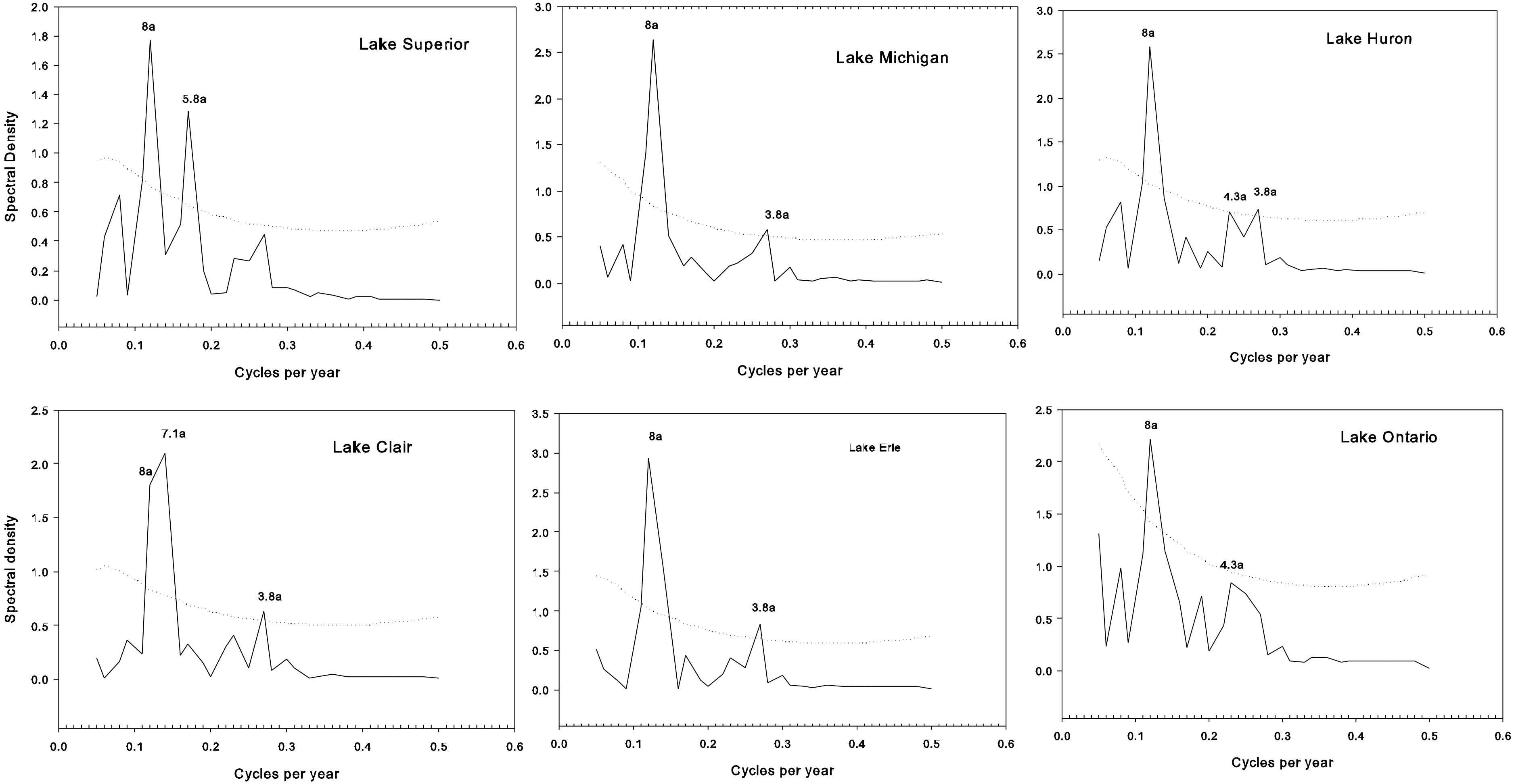


Spatial and temporal variability

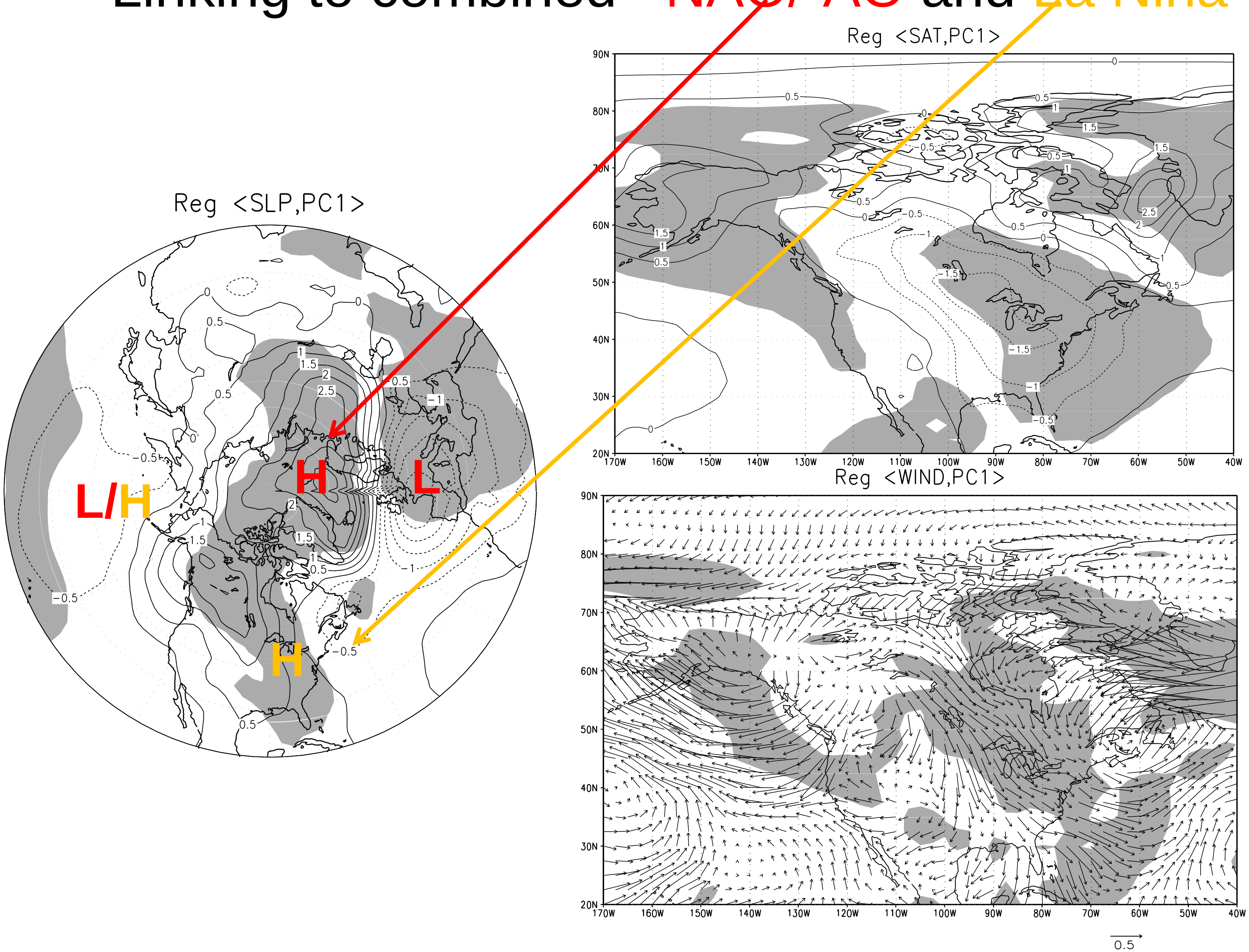
Mode 1: Ice cover in-phase response to climate forcing In all 6 lakes (dominant) with distinguished deep (small Coefs.) and shallow (large) lakes variability: indicating Water heat content plays an Important role!

Mode 2: Upper GL ice cover Is out of phase with lower GL with Huron at the center, except for Lake Ontario (since ice cover in L. Ontario is too small to be counted

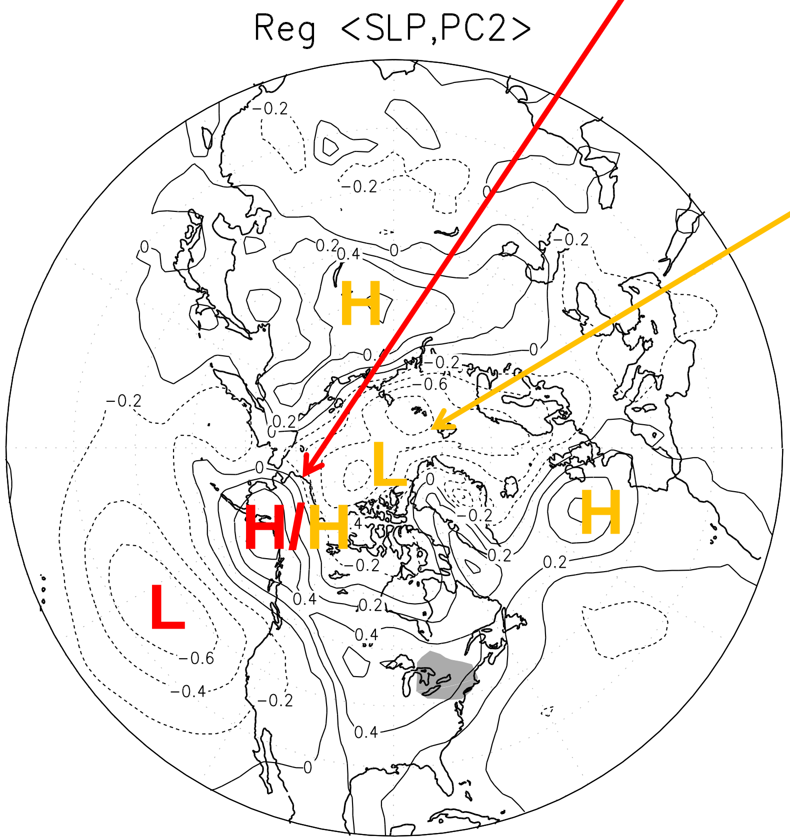
Periods: ~8 (quasi-decaldal) and 4 (interannual) years

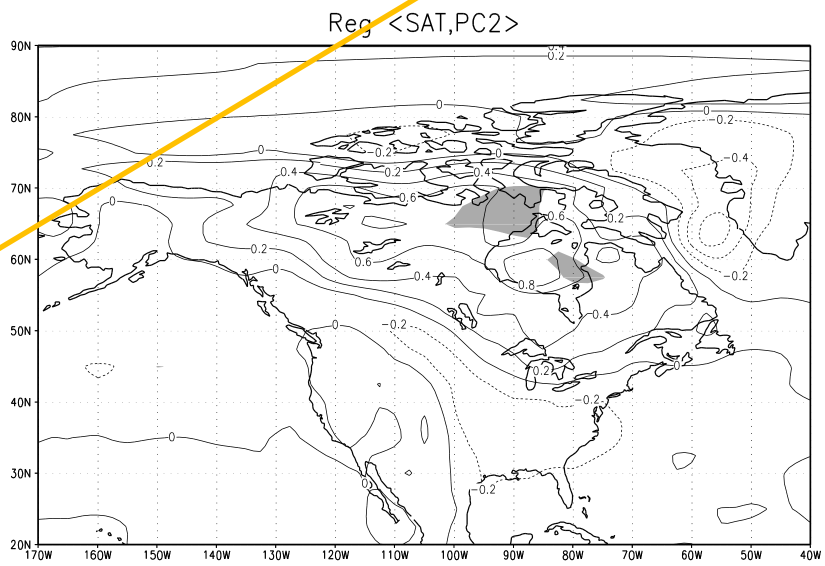


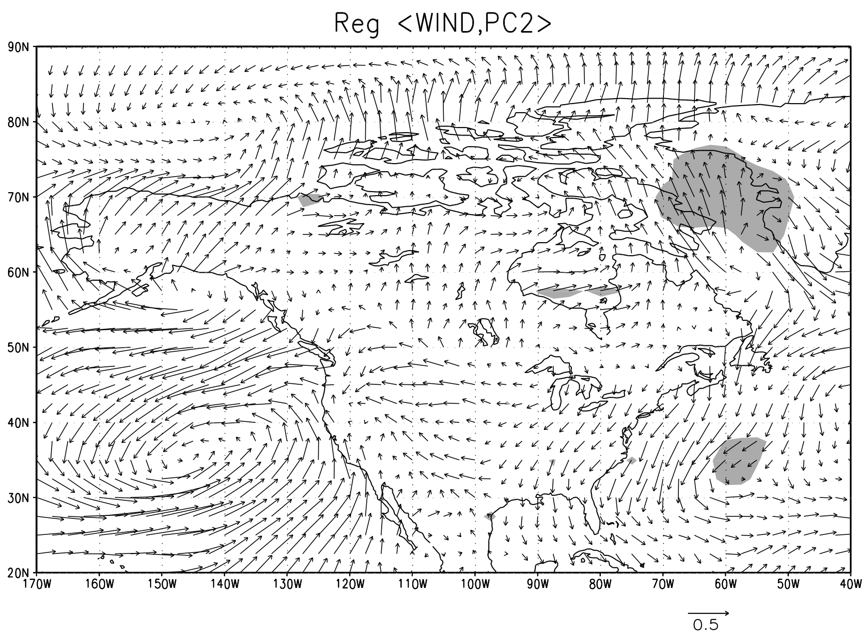
Regression of 1st EOF to SLP, SAT, and wind field: Linking to combined –NAO/-AO and La Nina



Regression of 2nd EOF to SLP, SAT, and wind field: Linking to East Pacific pattern and +NAO/AO

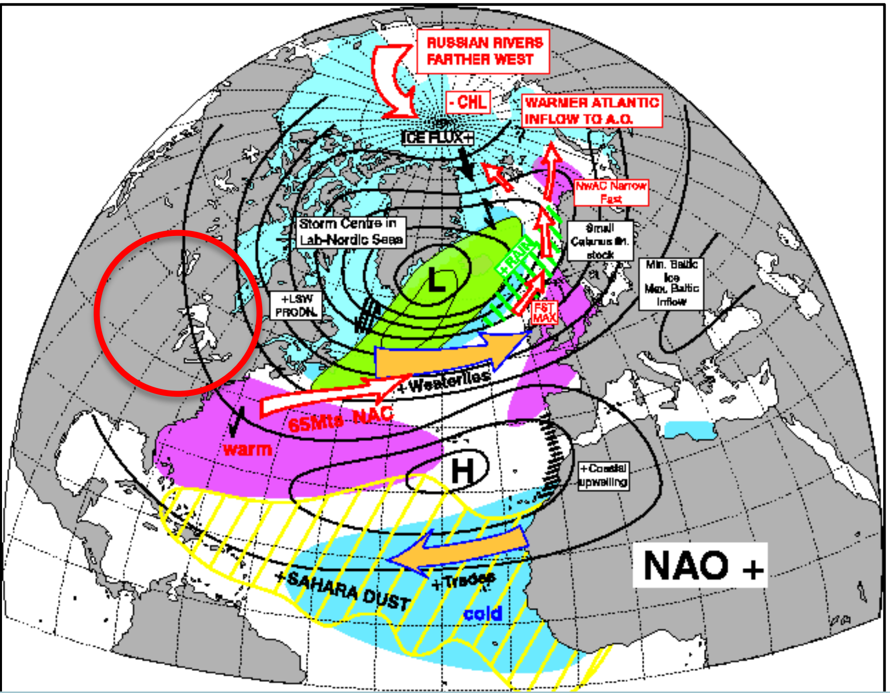


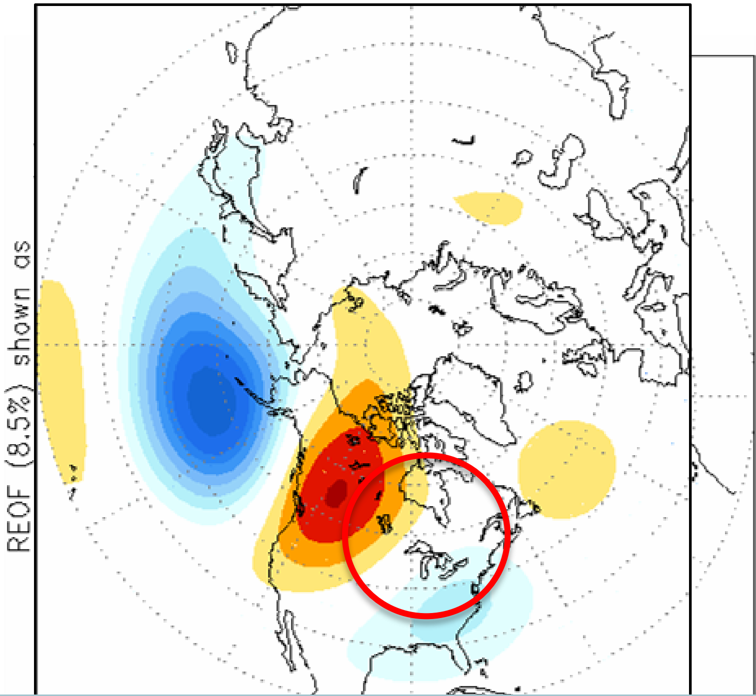




IV. Interference and combined effects of ENSO and AO

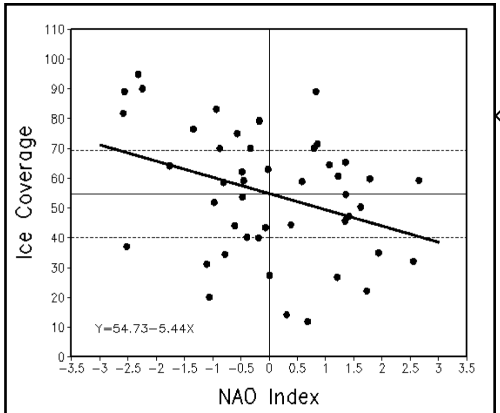
Lake ice signature of NAO/AO and ENSO





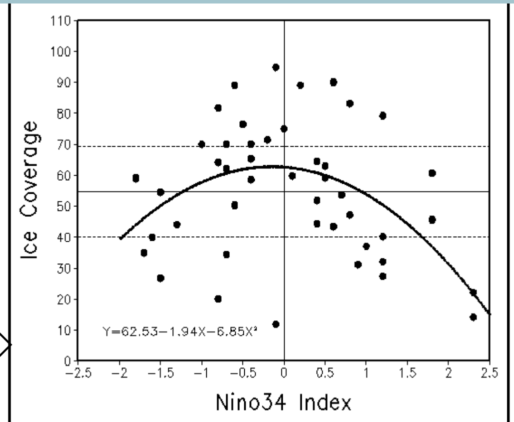
- **North Atlantic Oscillation (NAO) (Arctic Oscillation)**

Pacific North America Pattern (El Nino/La Nina, ENSO)



Ice and NAO:
Linear relationship

Ice and ENSO:
Nonlinear and asymmetric relationship

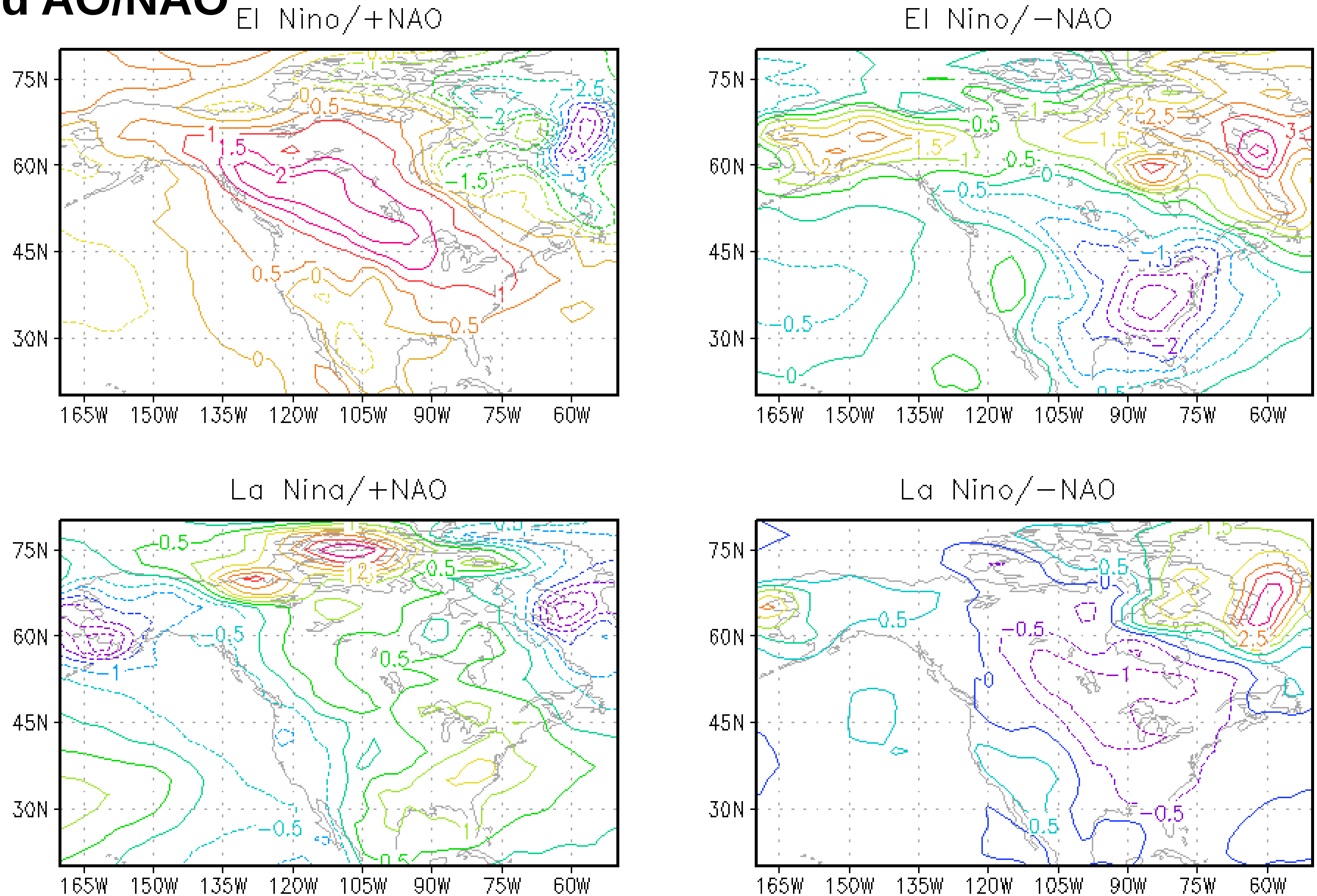


Classification of winters based on phases of ENSO and NAO

	+NAO	-NAO	NAO-Neutral
El Niño	*1973** 1983*1992* 1995* 2007 (41.4)	1964* 1969* 1970, 1977 1978	1966*,1987*,1988 1998*, *2003**, 2005
La Niña	1974* 1975 1989* 1999* 2000* 2008*	1963,1965, 1971*, 1985 1996 2001	1968, 1972 1976*
ENSO-Neutral	1967,1981,1984, 1990 1993 1994 2002	1979 1982, 1986, 1997 2004 2006	

Red is warm, blue is cold

emperature anomalies induced by combined effect of ENSO nd AO/NAO



V. Summary

1 Both ENSO and AO/NAO have impacts on the Great Lakes ice cover.

   a) El Nino events were often associated with less than normal Ice cover. La Nina events do not have significant impacts.

   b) -NAO events were associated with more ice cover.

2 The interference of effects of ENSO and NAO complicates the relationships, which should be considered when make predictions of ice cover.

Combined effects of ENSO and NAO/AO

	+AO/NAO (warm)	**-AO/NAO (cold)**
El Nino (warm)	**Extremely warm** 1973,1983,1992,1995,2007	Normal (to cold) 1966,1969
La Nina (cold at weak; but warm at strong)	Normal 1975 1976 1989 2000 2008	Cold during weak La Nina); Normal to warm during strong La Nina, ex. 2010/11) 1965 1985 2001

Summary (cont.)

3 Lake ice seasonal cycle has large STDs whose magnitudes are larger or equivalent to the seasonal mean, indicating a large natural variability and a poor long-term (>1 month to 1 year) predictability
4. Lake ice has strong quasi-decadal (~8 years) and weak interannual (~4 years) variability
5. Lake ice in all lakes respond to climate forcing/change at the same phase (80.8%), but with spatial variability between deep and shallow lakes , while the out-of-phase change in lake ice (10.7%) is between the Upper and Lower GLs with Huron as a central lake
6. Lake ice variability shows natural (interannual to quasi-decadal) and anthropogenic (trend) changes. Overall Great Lake ice loss in the past 40 years is -71%, ranging from -35% (St. Clair) to -88% (Ontario).

Questions?

- Jia Wang: jia.wang@noaa.gov

- Support: Great Lakes Restoration Initiative (GLRI) from EPA/NOAA on Theme Climate for Decision Making (Heather Stirratt)